EXOTIC DECAYS OF THE HIGGS BOSON

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On behalf of the CMS Collaboration

ICHEP2016: The 38th International Conference on High Energy Physics

Rare Decays of h(125)

With the discovery of the Higgs in the Run I of the LHC the long standing challenge "Where is the Higgs??" has evolved.

Is the new boson *really* the *minimal* SM Higgs?

Can we find new physics in the Higgs Sector?

CMS and ATLAS look extensively for answers to these two questions at high mass (searching for additional higgs bosons)

But what if new physics is hiding in the decays of the h(125) boson?

With BR(h→BSM)<0.34 still allowed from the combined CMS+ATLAS couplings analysis, there is plenty of room for new searches targeting exotic decays

In this talk…

- Run I left a large number of searches targeting rare/bsm decays of the h(125) Higgs
  - CMS is actively working in broadening the coverage for Run II with the full 2016 dataset
- Examples are the Invisible Higgs searches, **Lepton Flavor Violating decays of the Higgs**, and **h(125) decays to (pseudo)scalars** (which can be interpreted as a whole in a general **2HDM+S model -**with one extra CP even scalar s and one extra CP odd scalar a **-** but also specifically in NMSSM or Dark Susy scenarios)

h→aa→2μ2b (CMS-PAS-HIG-14-041)
h→aa→4μ (Phys. Lett. B 752 (2016) 221)
h→aa→2μ2τ (CMS-PAS-HIG-15-011
h→aa→4τ (CMS-PAS-HIG-14-022, CMS:JHEP 01 (2016) 079)

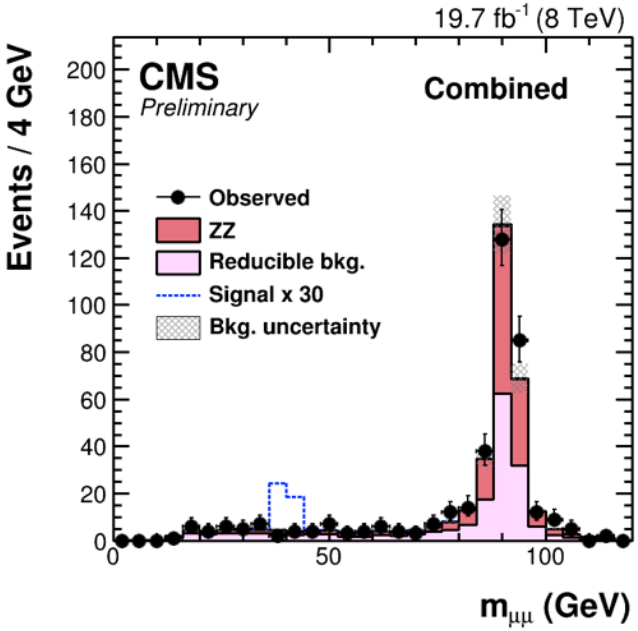
LFV h→ll' (Phys. Lett. B 749 (2015) 337 , CMS-HIG-14-040, CMS-HIG-16-005)

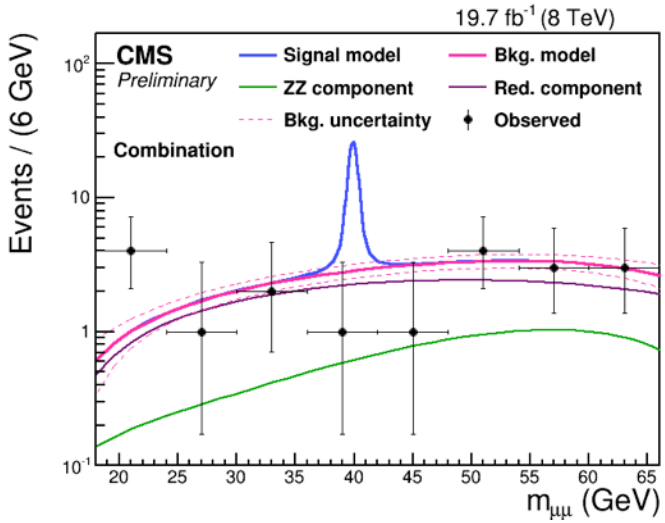
Searches for Higgs decays to invisible particles in CMS covered by **N. Wardle**
Searches for low mass (pseudo) scalars (!=h(125)) will be covered by **C. Carrillo**

$h(125) \rightarrow aa$

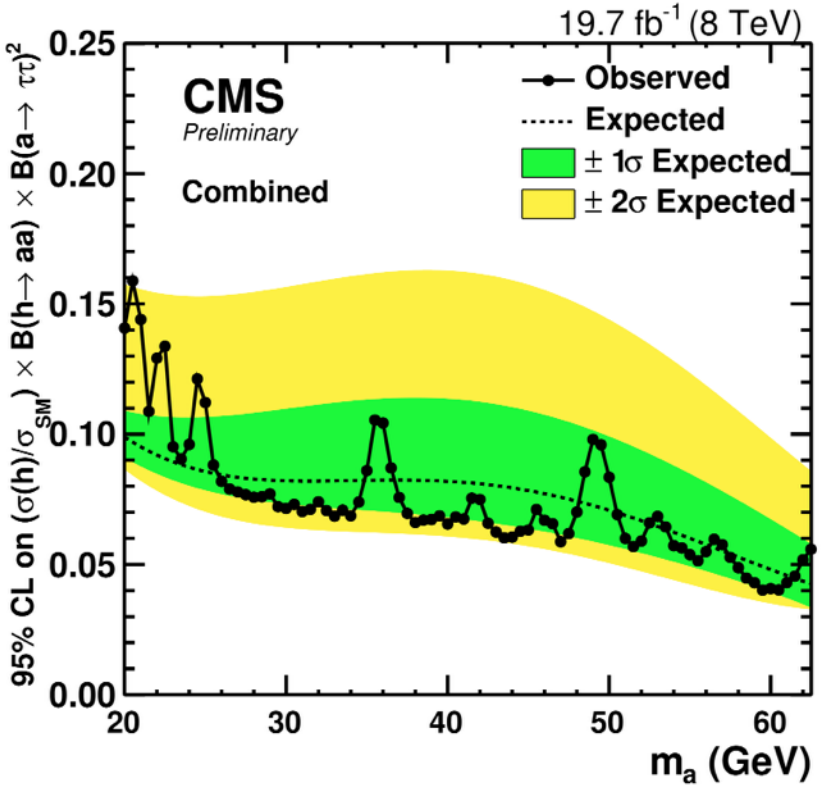
h→aa→μμττ

CMS-PAS-HIG-15-011



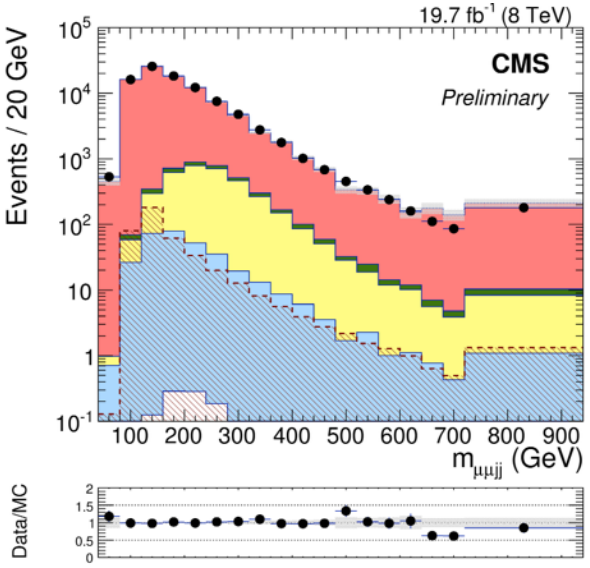


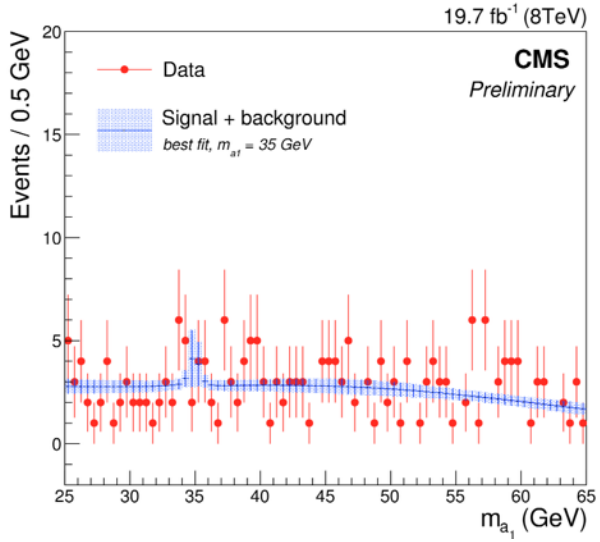
- 2HDM+S interpretation (general and specific for type III at high tanβ and type IV at low tanβ)
- Categorised depending on the tau decay ($\tau_e\tau_e$, $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_e\tau_\mu$, $\tau_h\tau_h$)
- Signal discrimination through a fit to the dimuon distribution (good mass resolution)



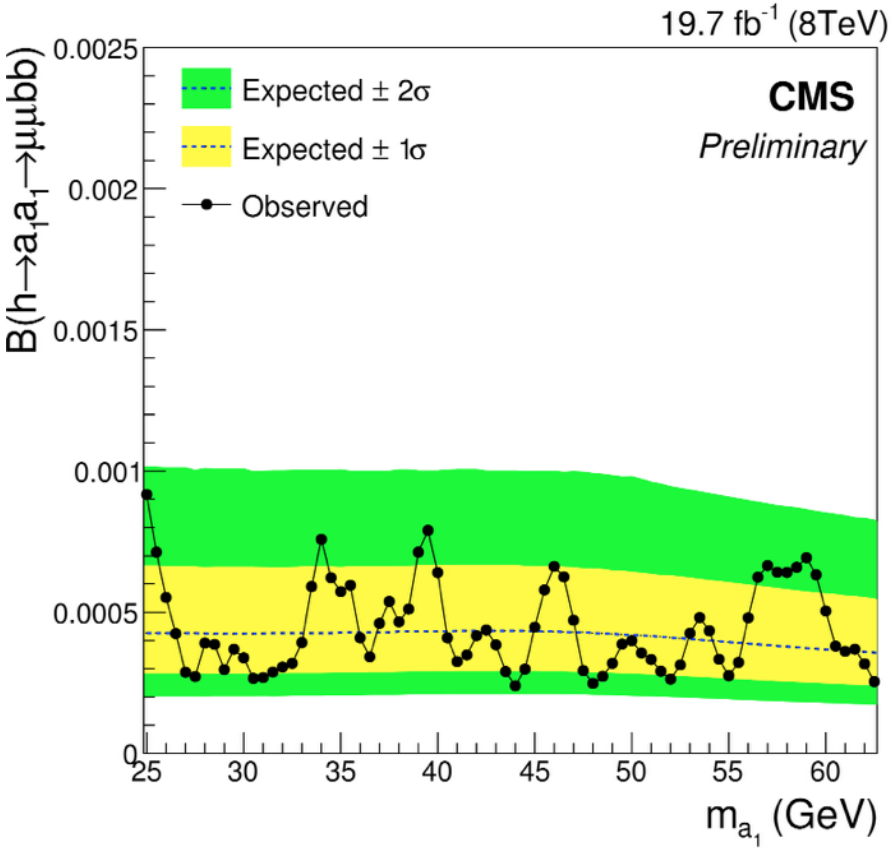
h→aa→μμbb

CMS-PAS-HIG-14-041





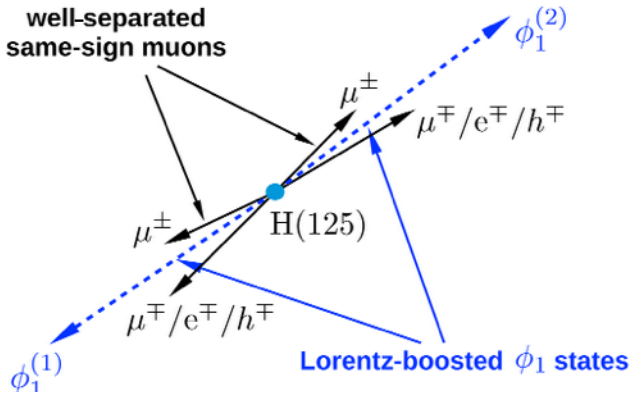
- Signal discrimination through a fit to the dimuon distribution (good mass resolution)
- Focus on a NMSSM interpretation

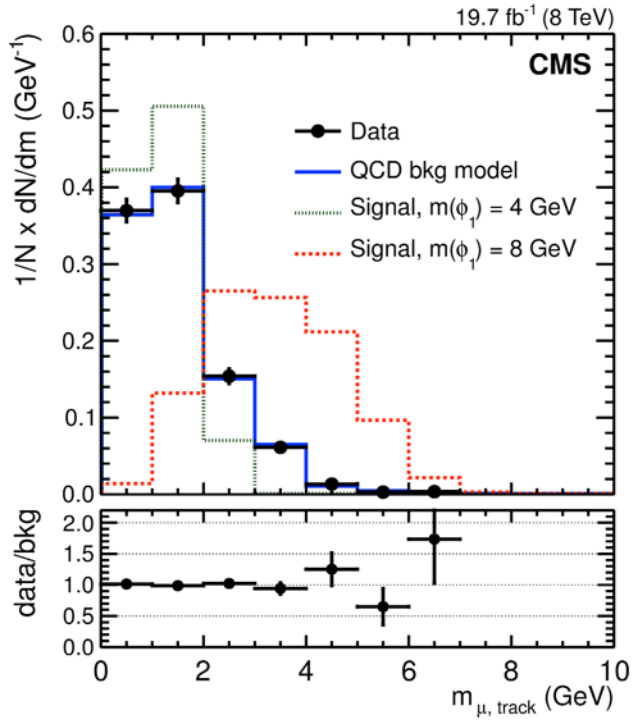


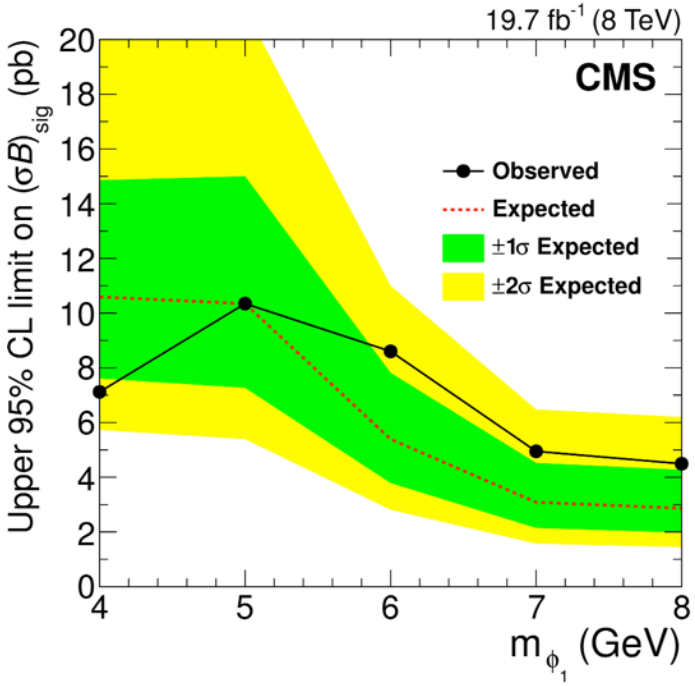
h→aa→4τ (I)

CMS-PAS-HIG-14-019
JHEP 01 (2016) 079

- Mass discrimination through **muon+track** combinations to target a low mass range: 4-8 GeV
- Exploit the presence of **same sign muons** to reduce background contribution
- Signal extraction through maximum-likelihood fit to the 2D distribution of $m_{\mu track}(1)$ vs $m_{\mu track}(2)$





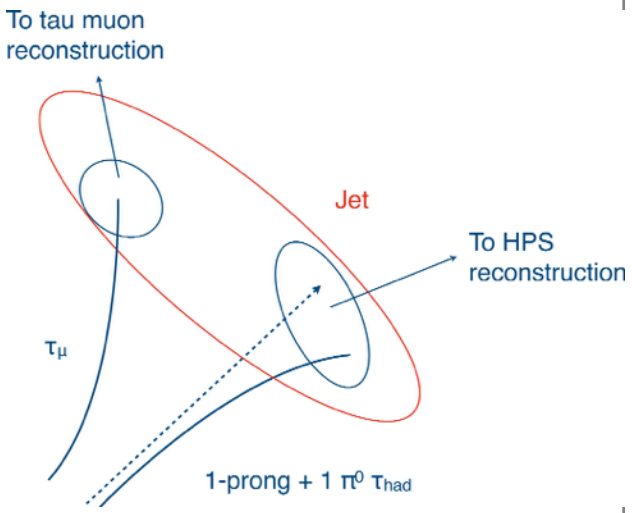


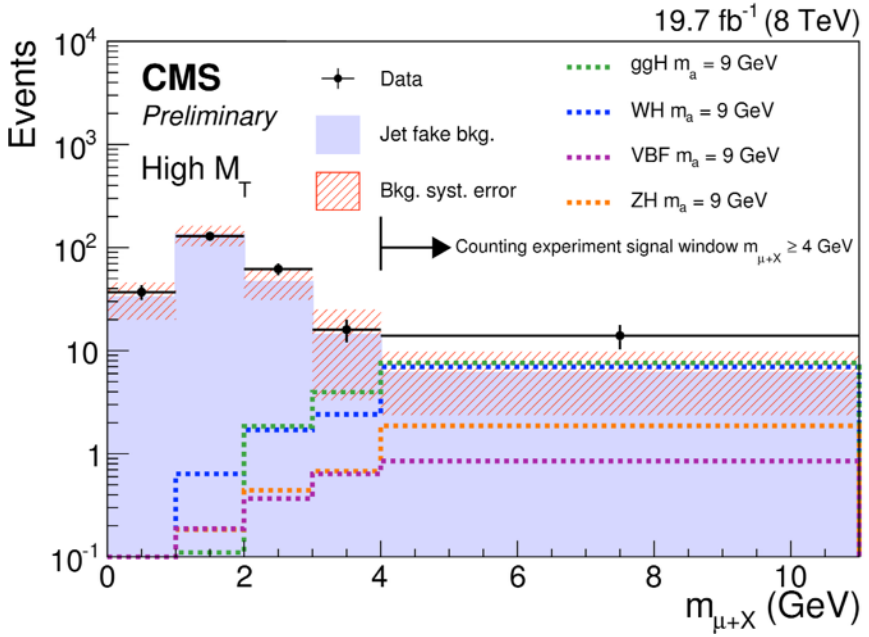
$$(\sigma\mathcal{B})_{\text{sig}} \equiv \sigma(gg \to \mathrm{H}(125))\,\mathcal{B}(\mathrm{H}(125) \to \phi_1\phi_1)\,\mathcal{B}^2(\phi_1 \to \tau\tau),$$

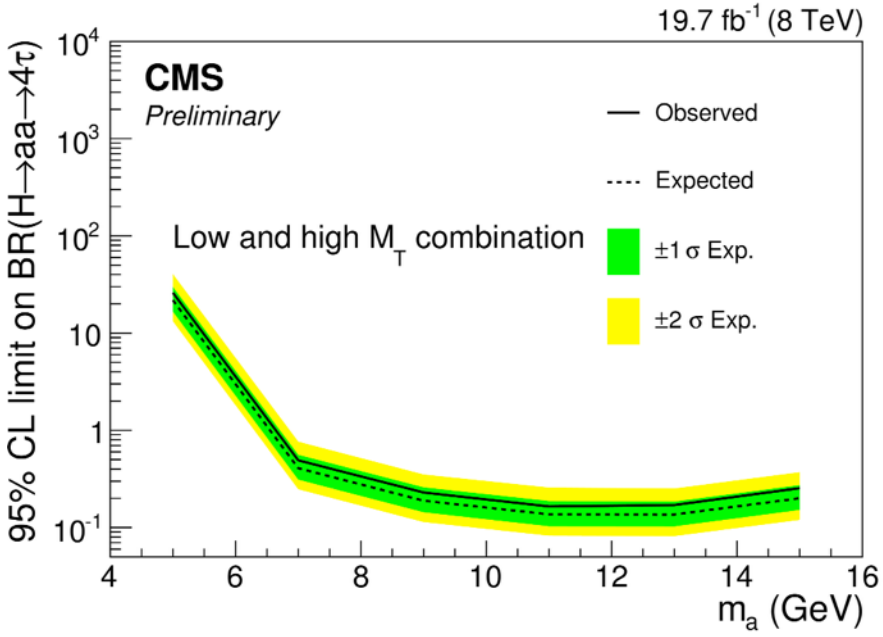
h→aa→4τ (II)

CMS-PAS-HIG-14-022

- Higher mass range covered (5-15 GeV), can look for hadronic taus (Muon+Hadronic tau combinations)
- Two categories in M_T
  - Low Mass targets GGF and VBF production
  - High M_T targets WH production



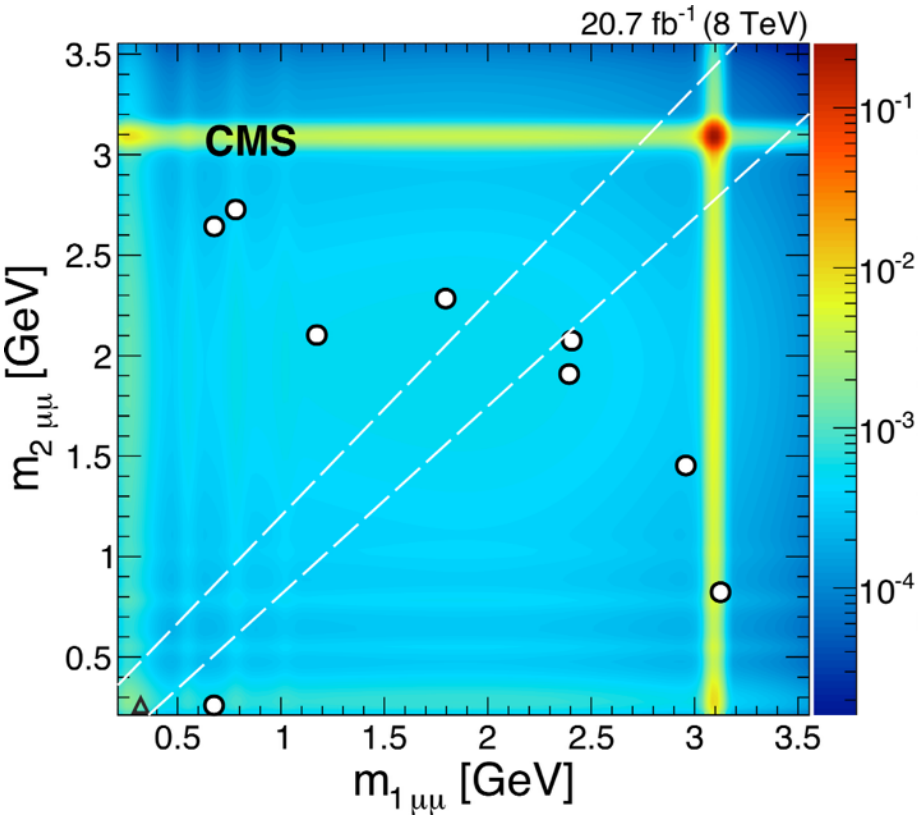


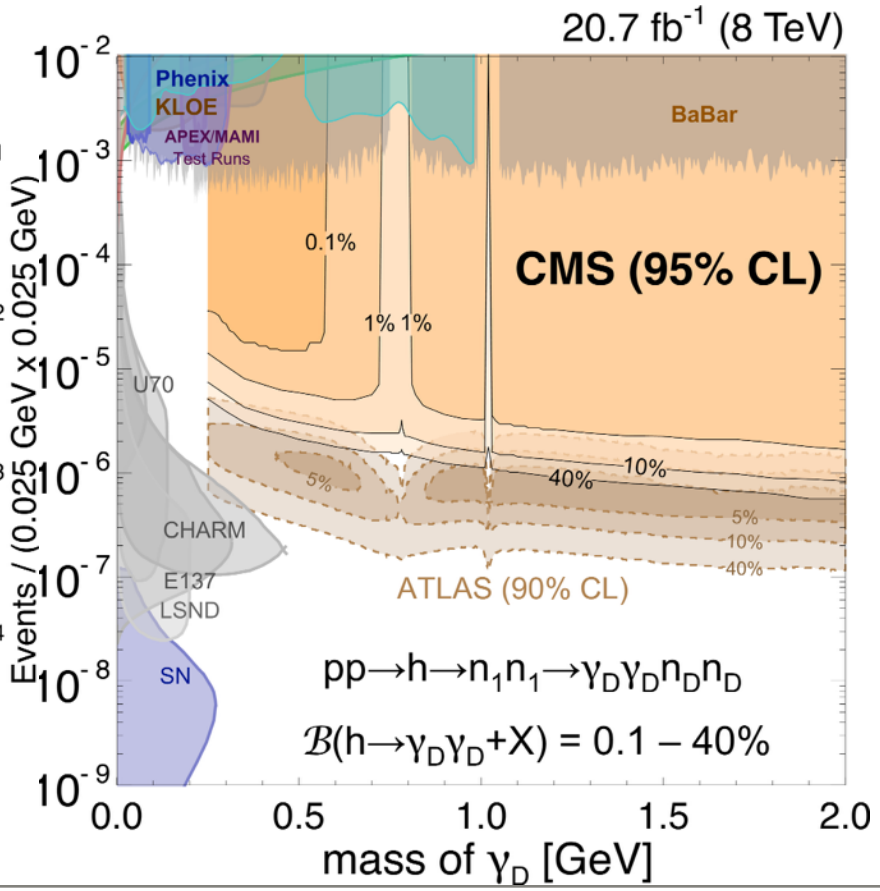


h→aa→4μ

- Both model dependent (Dark Susy and NMSSM) and model independent interpretations
- Background dominated by bb and J/Ψ events
  - Data driven determination of backgrounds
- Very low mass range: 0.25-3.55 GeV

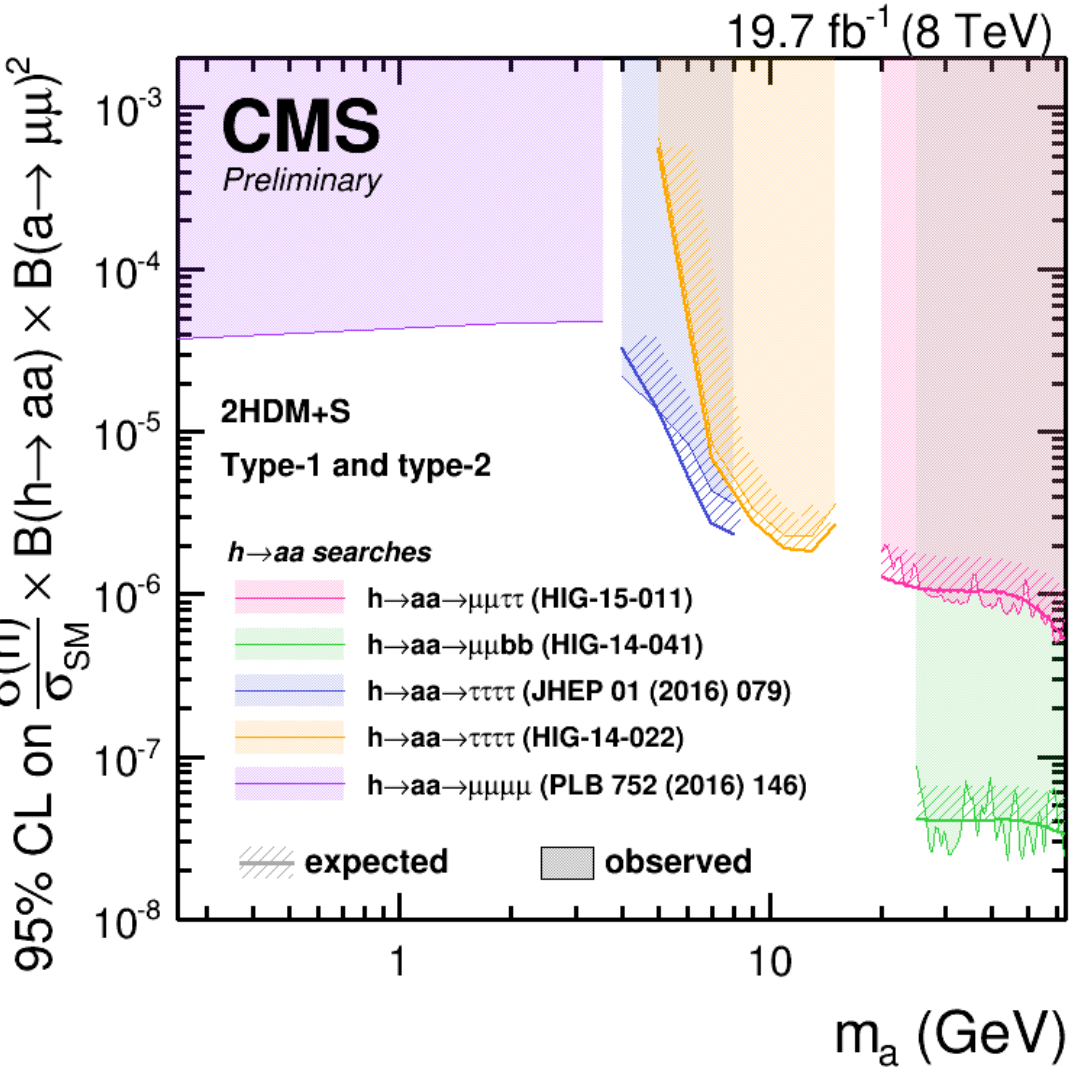
CMS-HIG-13-010
PLB 752 (2016) 146

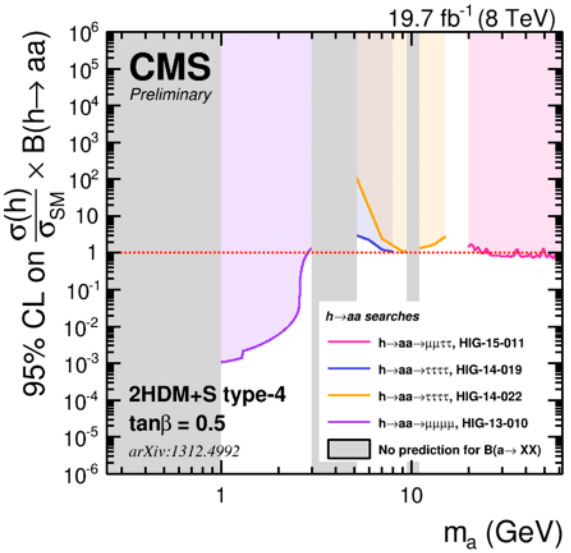


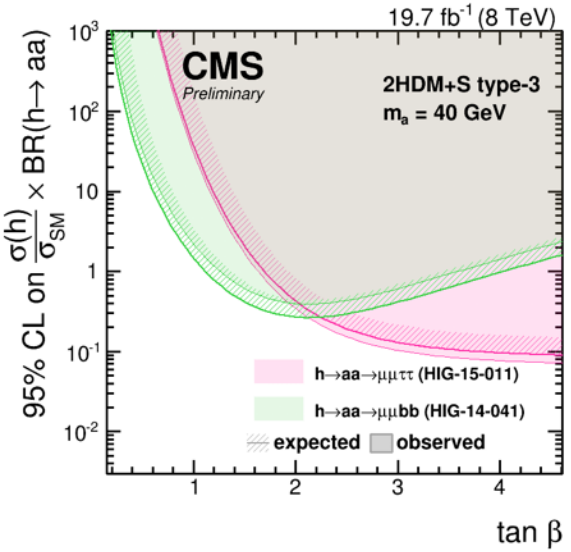


2HDM+S Summary

- Joint interpretation of the different searches







LFV h(125)

H→lτ and H→eμ

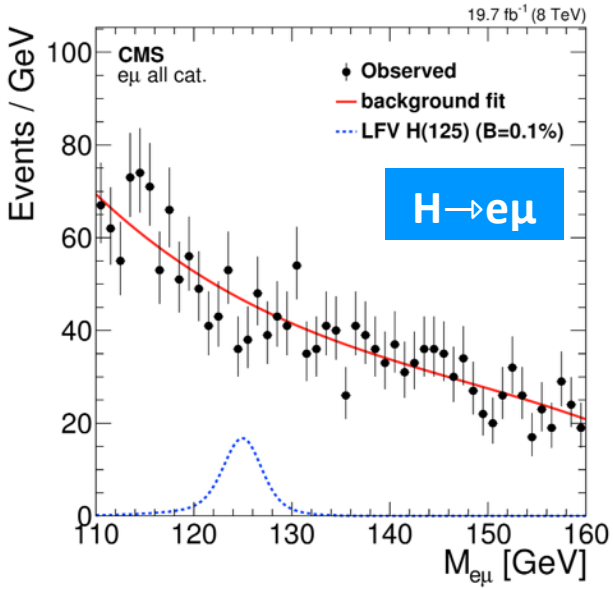
- Complementary to the SM Hττ and Hμμ searches
- Probe the off-diagonal Higgs yukawa couplings

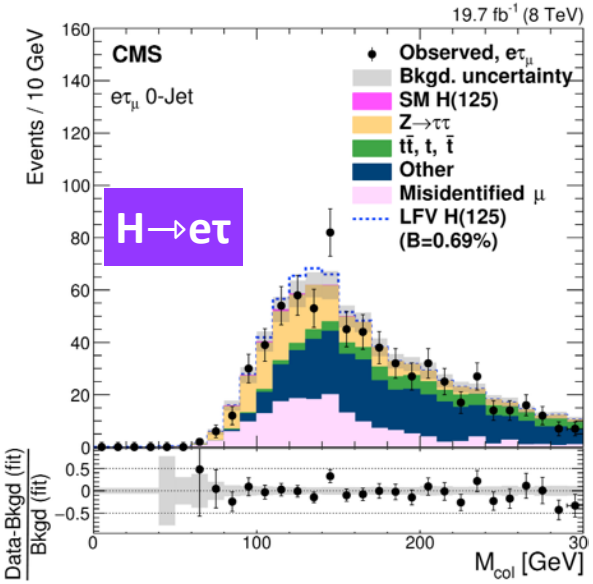
H→eμ

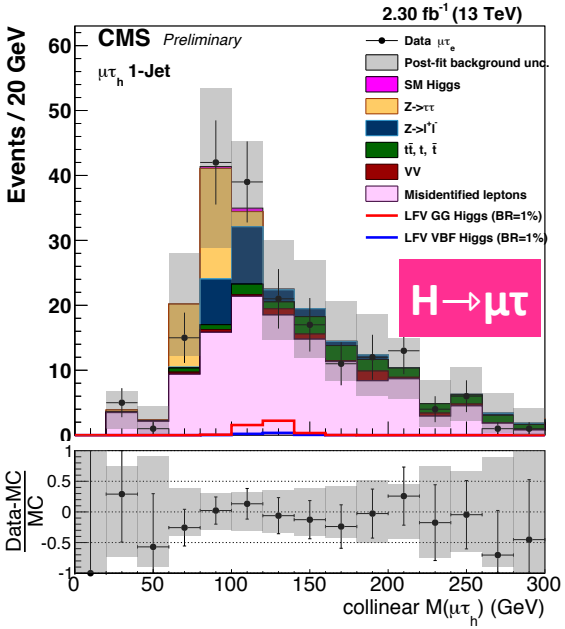
- Very clean - but targeting highly constrained Br!
- **10 Categories** (Barrel/Endcap Leptons; jet bins)
- Functional fit to the electron-muon inv. mass

H→lτ

- 2 channels ($l\tau_{l'}$, $l\tau_{had}$), 3 categories (0-1-2 Jets)
- Large background: Leading systematic uncertainties background modelling
- Template fits to the collinear mass distribution

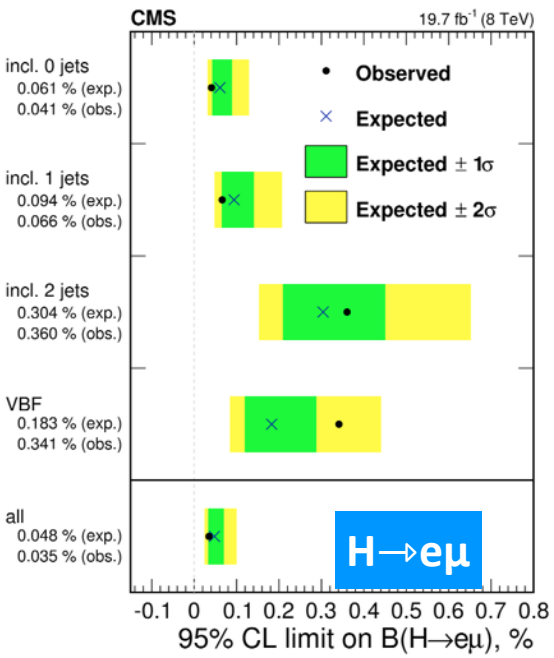


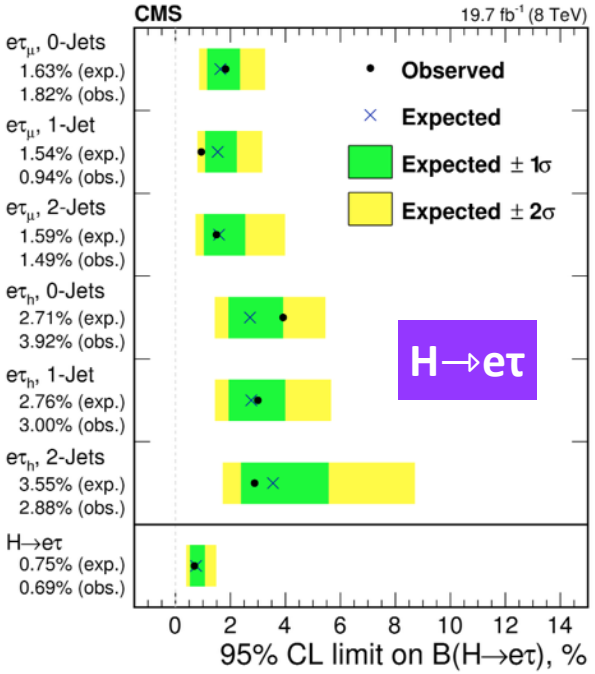


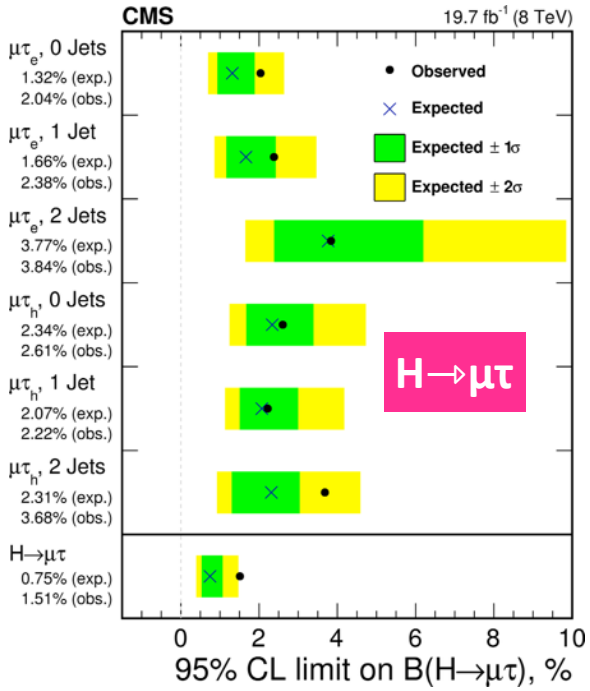


Phys. Lett. B 749 (2015) 337 | **HIG-14-040 (arXiv:1607.03561)** | **HIG-16-005 (2015 data)**

Run I 95%CL Limits





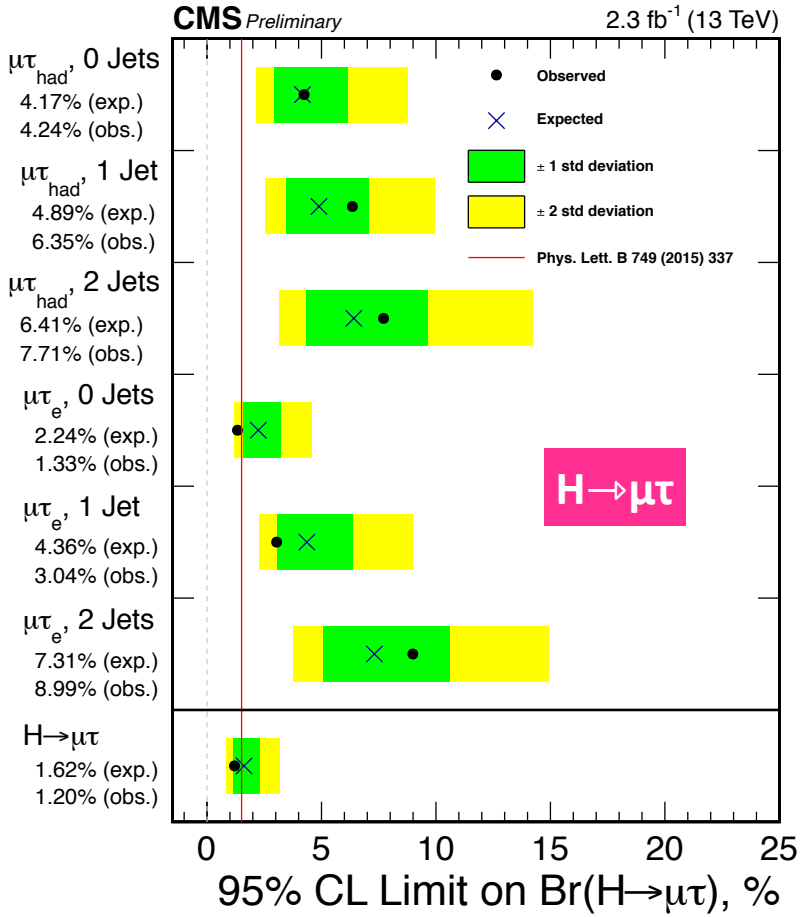


Br(H→eμ)<0.36e-3 (0.48e-3 expected)

Br(H→eτ)<0.69% (0.75% expected)

Br(H→μτ)<1.51% (0.75% expected)

Run II: First Look (2015 dataset)



Expected limits				
	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
$\mu\tau_h$	<4.17	<4.89	<6.41	<2.98
$\mu\tau_e$	<2.24	<4.36	<7.31	<1.96
$\mu\tau$	<1.62 %			

Observed limits				
	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
$\mu\tau_h$	<4.24	<6.35	<7.71	<3.81
$\mu\tau_e$	<1.33	<3.04	<8.99	<1.15
$\mu\tau$	<1.20 %			

Best-fit branching fractions				
	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
$\mu\tau_h$	$0.12^{+2.02}_{-1.91}$	$1.70^{+2.41}_{-2.52}$	$1.54^{+3.12}_{-2.71}$	$1.12^{+1.45}_{-1.40}$
$\mu\tau_e$	$-2.11^{+1.30}_{-1.89}$	$-2.18^{+1.99}_{-2.05}$	$2.04^{+2.96}_{-3.31}$	$-1.81^{+1.07}_{-1.32}$
$\mu\tau$	$-0.76^{+0.81}_{-0.84}$ %			

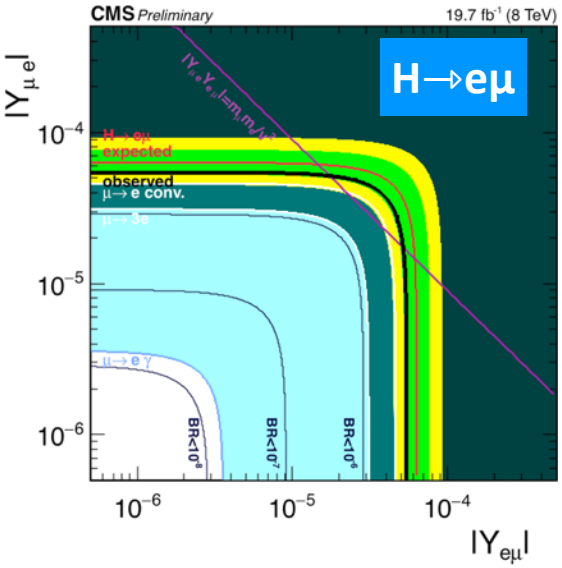
Br(H→μτ)<1.20% (1.62% expected)

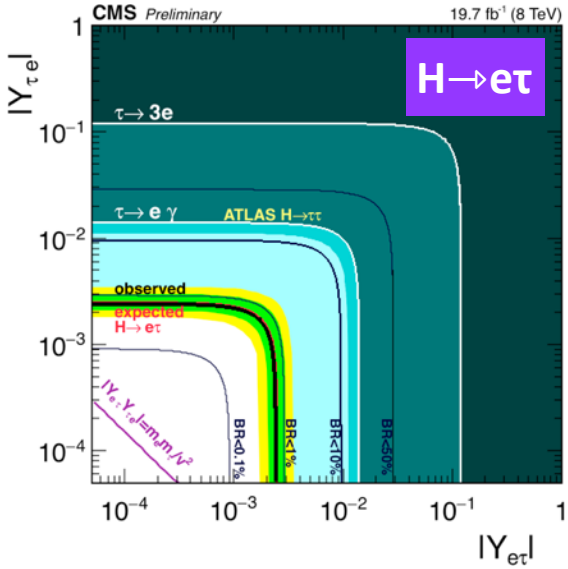
- No excess observed, but not sensitive enough to exclude the 8TeV result

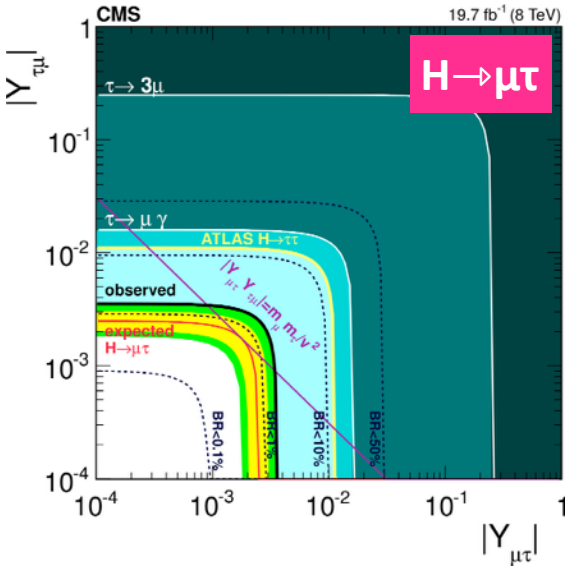
Limits on the Higgs Yukawa couplings

Channel	Coupling	95% CL Limit	
		Pre-LHC	CMS
$H\to \mu e$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$3.6 \cdot 10^{-6}$	$5.4 \cdot 10^{-4}$
$H\to \mu\tau$	$\sqrt{\lvert Y_{\mu\tau}\rvert^2 + \lvert Y_{\tau\mu}\rvert^2}$	0.016	0.0036(*)
$H\to e\tau$	$\sqrt{\lvert Y_{e\tau}\rvert^2 + \lvert Y_{\tau e}\rvert^2}$	0.014	0.0024

(* 0.0032 w. 2015)







Summary

- The SM-like Higgs boson discovery opens a era of precision physics
  - → **Comprehensive set of production and decay measurements performed using the 7 and 8 and 13 TeV CMS data**
  - → **Searches in rarer modes become sensitive enough for discovery**

- **Different searches for higgs decays to low-mass (pseudo) scalars performed with CMS Run-I data**
  - **Large phase-space coverage: decay modes involving bs, μ, τ**
  - **Targeting NMSSM and 2HDM+S decay modes**
  - **Ongoing Run II searches will broaden the channels and masses probed**

- **First direct searches for LFV Higgs decays, in the three decay channels: μτ, μe, eτ, performed by CMS**
  - **Slight excess of the CMS 8TeV result not confirmed (but not excluded) by the first preliminary 13TeV results**
  - No deviation from the background-only hypothesis is observed for the **eτ channel or μe channels**

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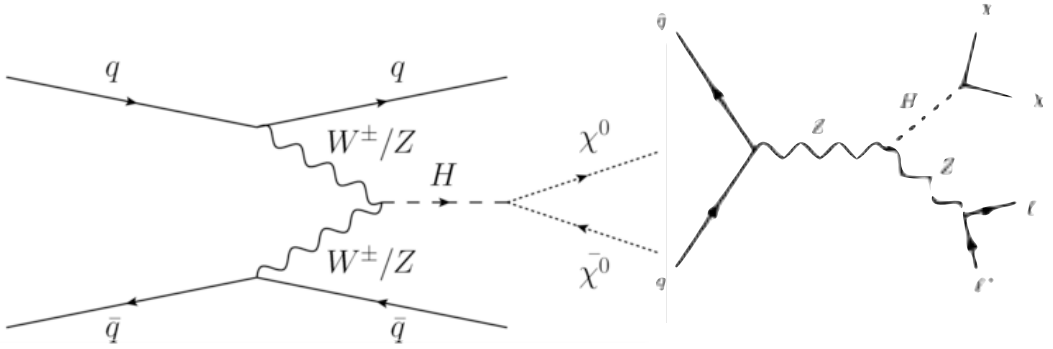
Enjoy ICHEP and stay
tuned for more 2016 results - very soon!

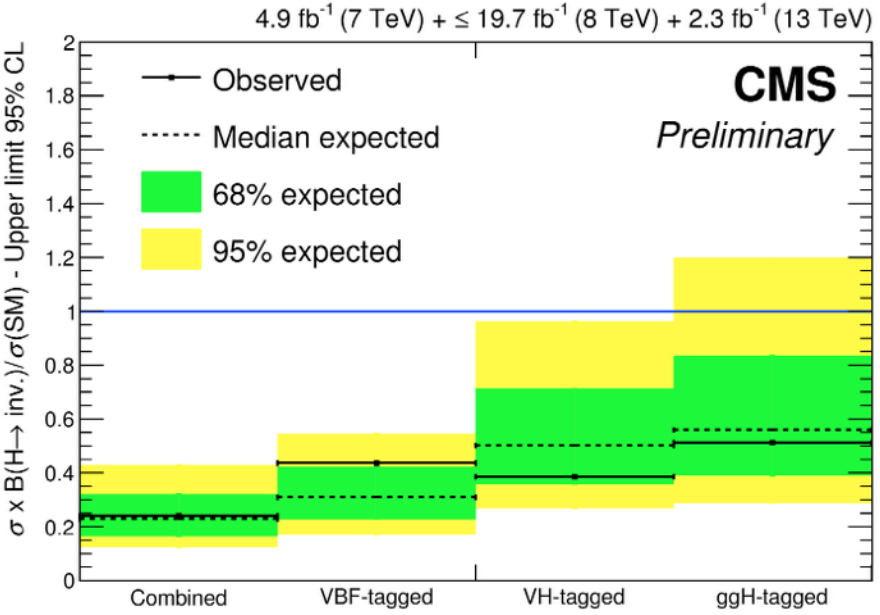
Backup

Invisible Higgs Decays

Higgs decays to undetected particles → **connection to Dark Matter Searches**

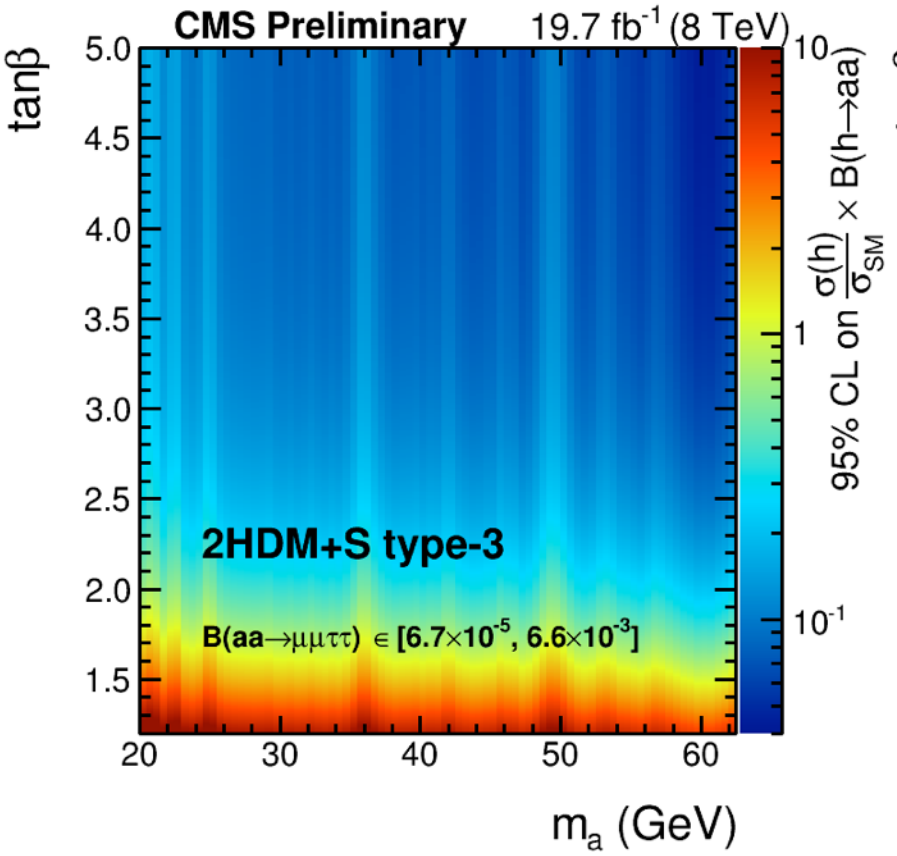


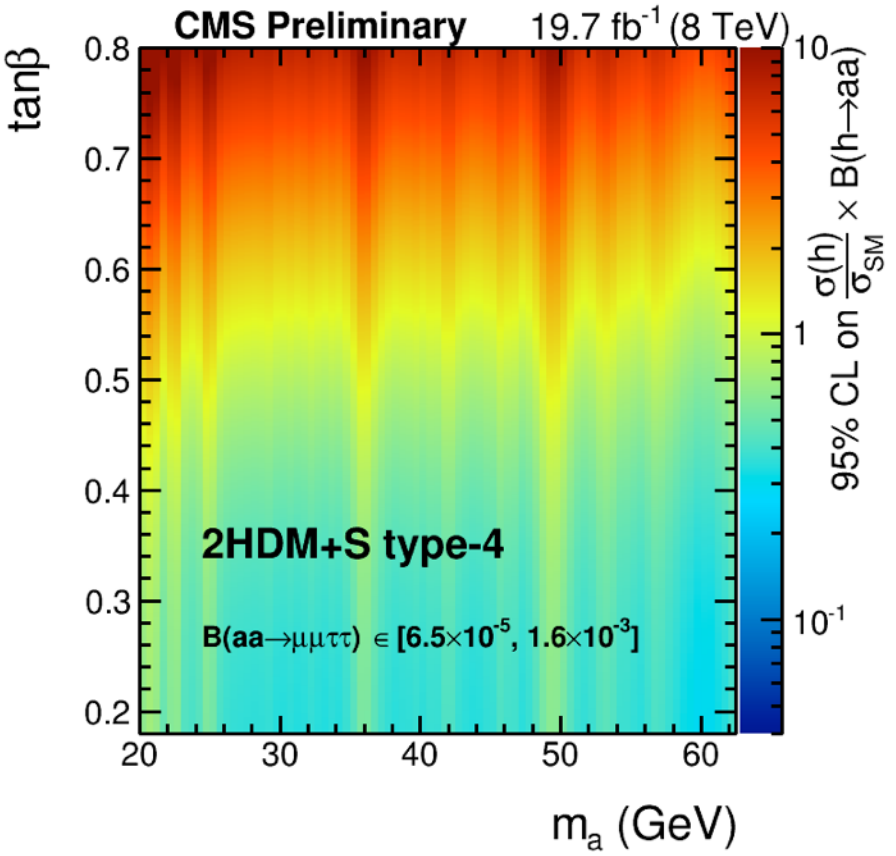
Summary: 95% CL limit on BR for M 125 GeV	
CMS HIG-15-012: Run I Combination	<36(30%)
CMS HIG-16-016: Run I + 2015 Combination	<24 (23%)



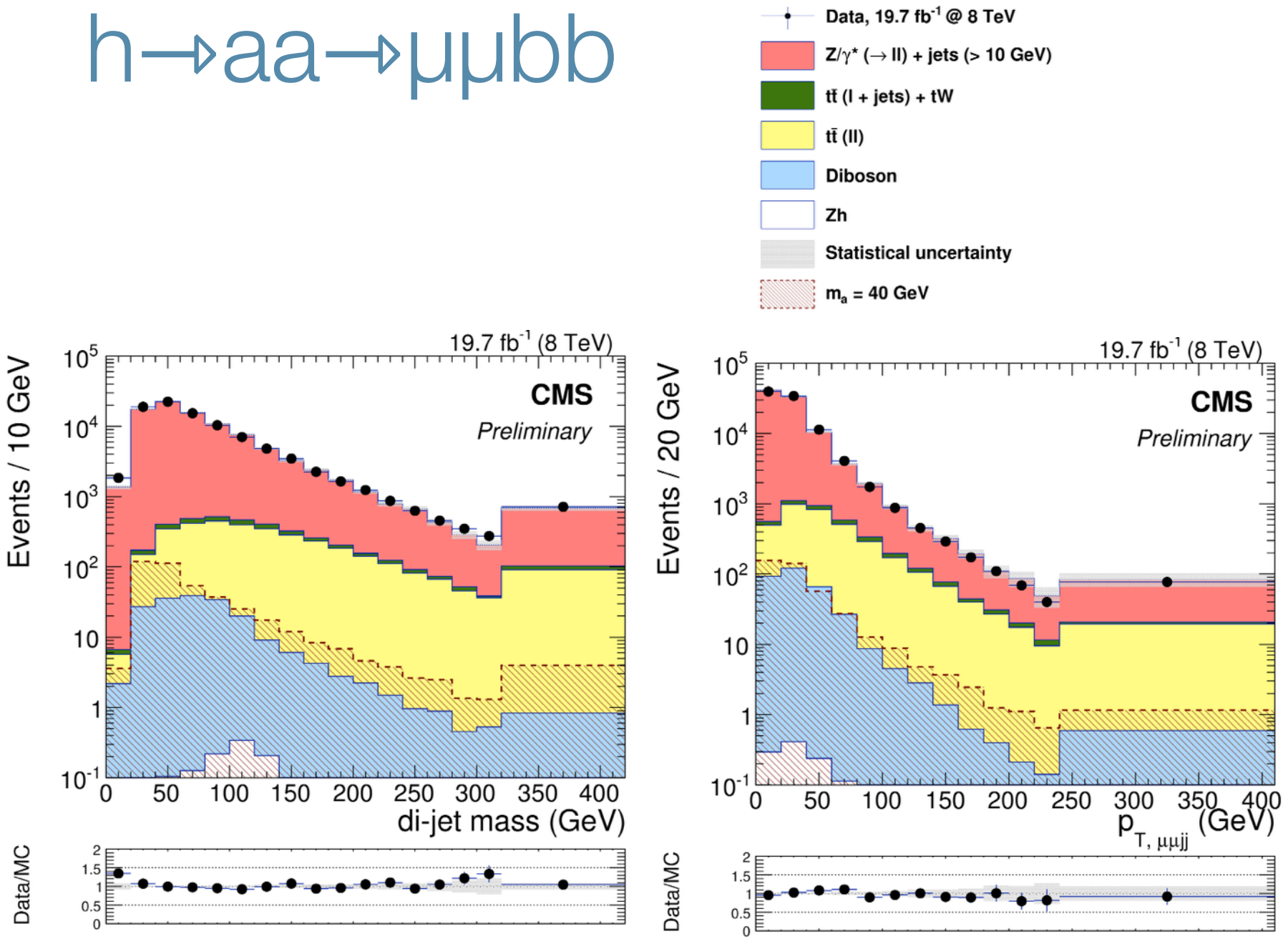
SEE TALK BY NICK WARDLE

h→aa→μμττ

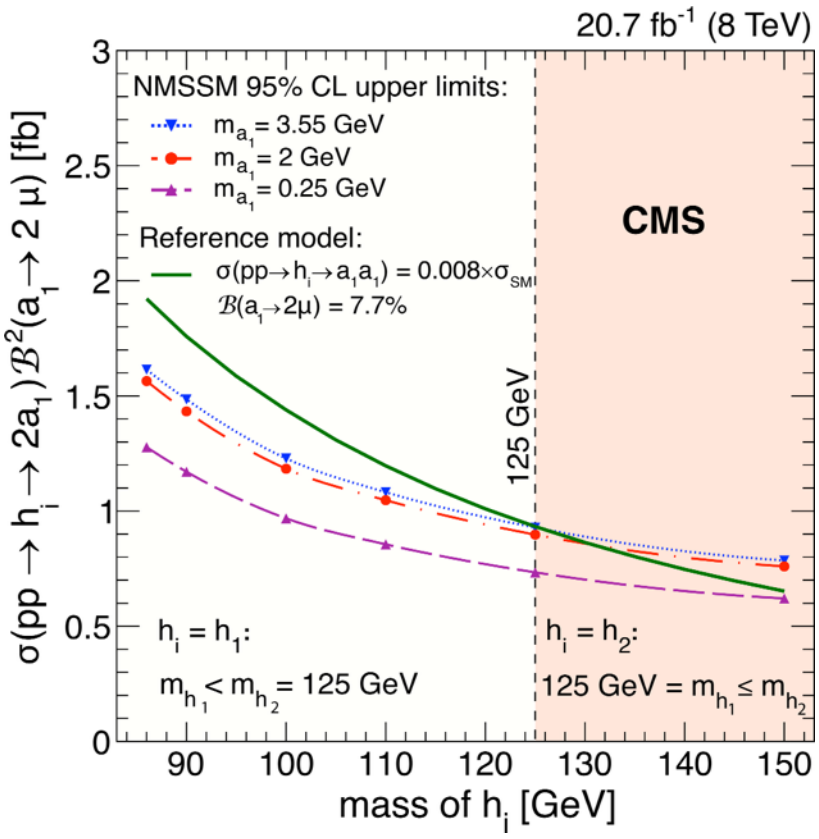

CMS Preliminary
19.7 fb-1 (8 TeV)
tanβ
2HDM+S type-3
B(aa→μμττ) ∈ [6.7×10-5, 6.6×10-3]
95% CL on σ(h)/σSM × B(h→aa)
ma (GeV)

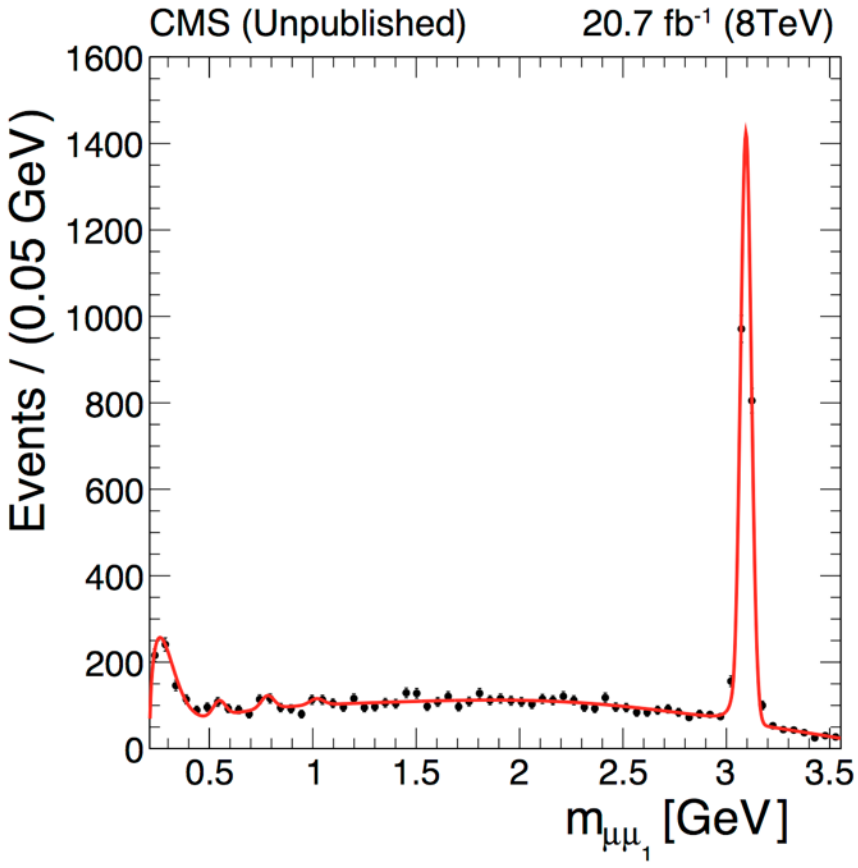

CMS Preliminary
19.7 fb-1 (8 TeV)
tanβ
2HDM+S type-4
B(aa→μμττ) ∈ [6.5×10-5, 1.6×10-3]
95% CL on σ(h)/σSM × B(h→aa)
ma (GeV)

h→aa→μμbb


Data, 19.7 fb-1 @ 8 TeV
Z/γ* (→ ll) + jets (> 10 GeV)
tt̄ (l + jets) + tW
tt̄ (ll)
Diboson
Zh
Statistical uncertainty
ma = 40 GeV
19.7 fb-1 (8 TeV)
CMS
Preliminary
Events / 10 GeV
di-jet mass (GeV)
Data/MC
19.7 fb-1 (8 TeV)
CMS
Preliminary
Events / 20 GeV
pT, μμjj (GeV)
Data/MC

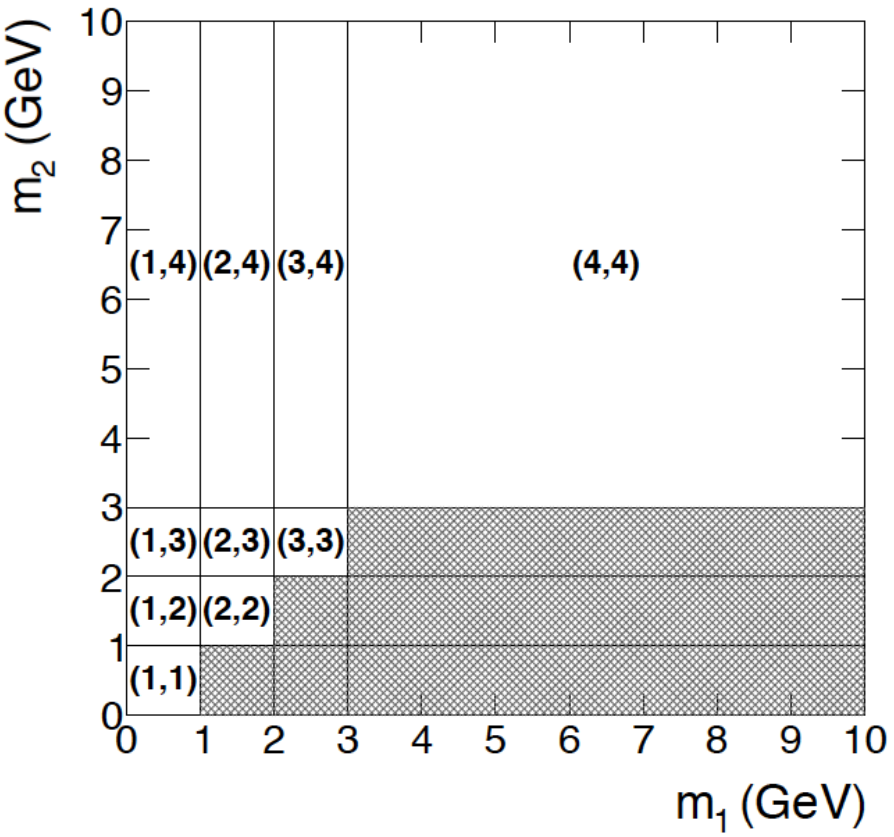
h→aa→4μ

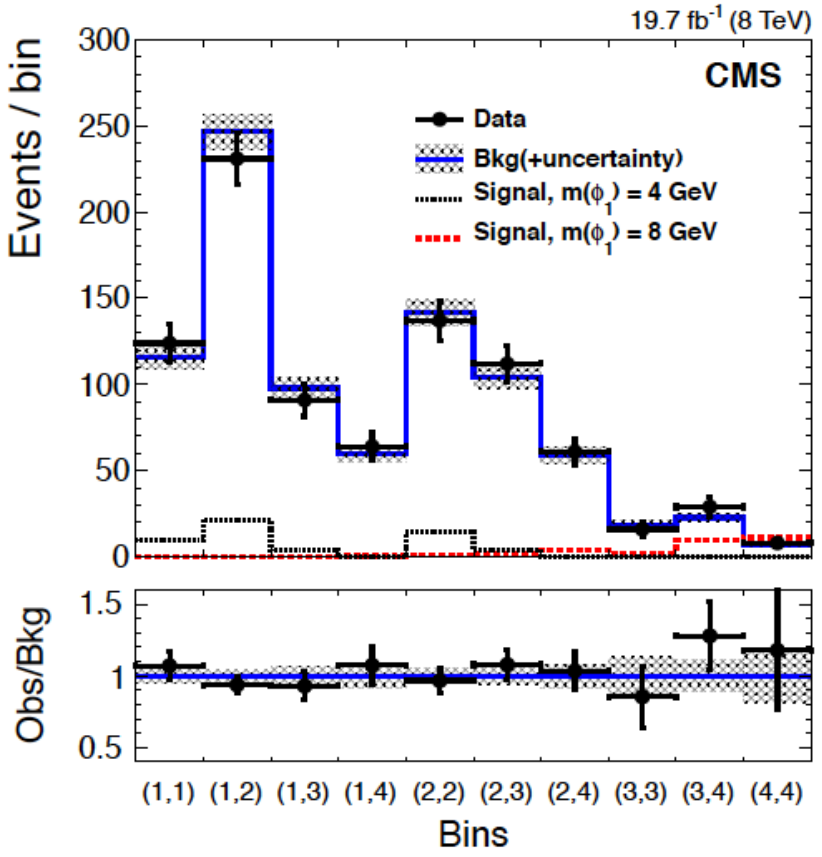

20.7 fb-1 (8 TeV)
NMSSM 95% CL upper limits:
ma1 = 3.55 GeV
ma1 = 2 GeV
ma1 = 0.25 GeV
Reference model:
σ(pp→hi→a1a1) = 0.008×σSM
ℬ(a1→2μ) = 7.7%
CMS
125 GeV
hi = h1:
mh1 < mh2 = 125 GeV
hi = h2:
125 GeV = mh1 ≤ mh2
σ(pp → hi → 2a1)ℬ2(a1→ 2 μ) [fb]
mass of hi [GeV]


CMS (Unpublished)
20.7 fb-1 (8TeV)
Events / (0.05 GeV)
mμμ1 [GeV]

h→aa→4τ (low mass)

- 2D Fit - bins of $m_{\mu track}(1)$ vs $m_{\mu track}(2)$





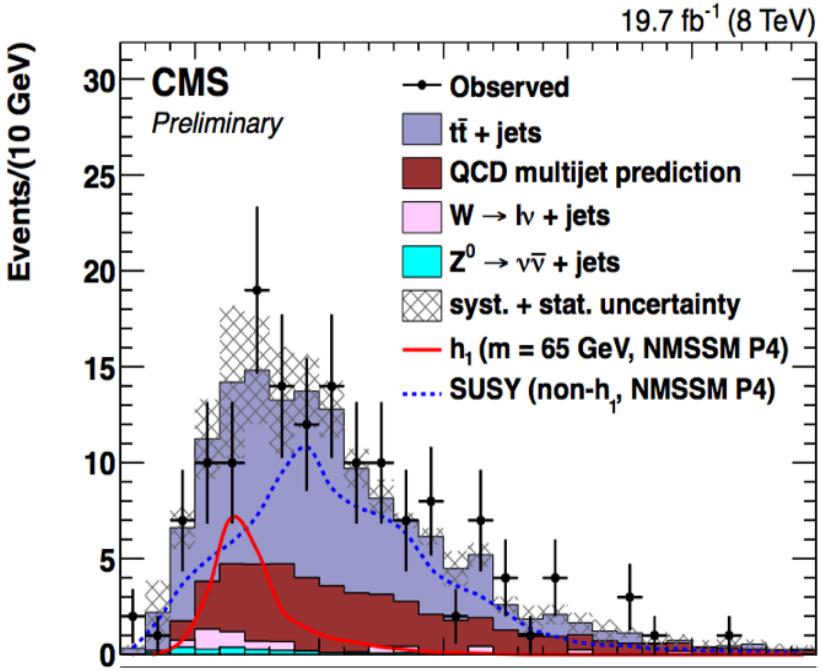
NMSSM light scalar $h_1 \rightarrow bb$

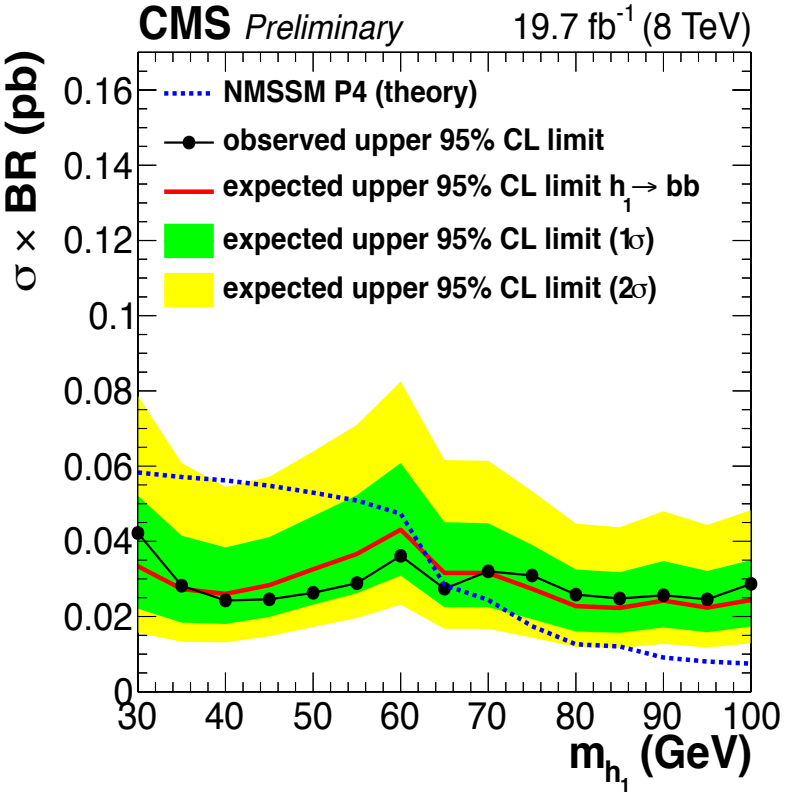
- Lightest scalar (h_1) in the NMSSM can be lighter than M_h=125 GeV
- Interpretation in the context of the NMSSM P4

Signature: 2 bjets and MET

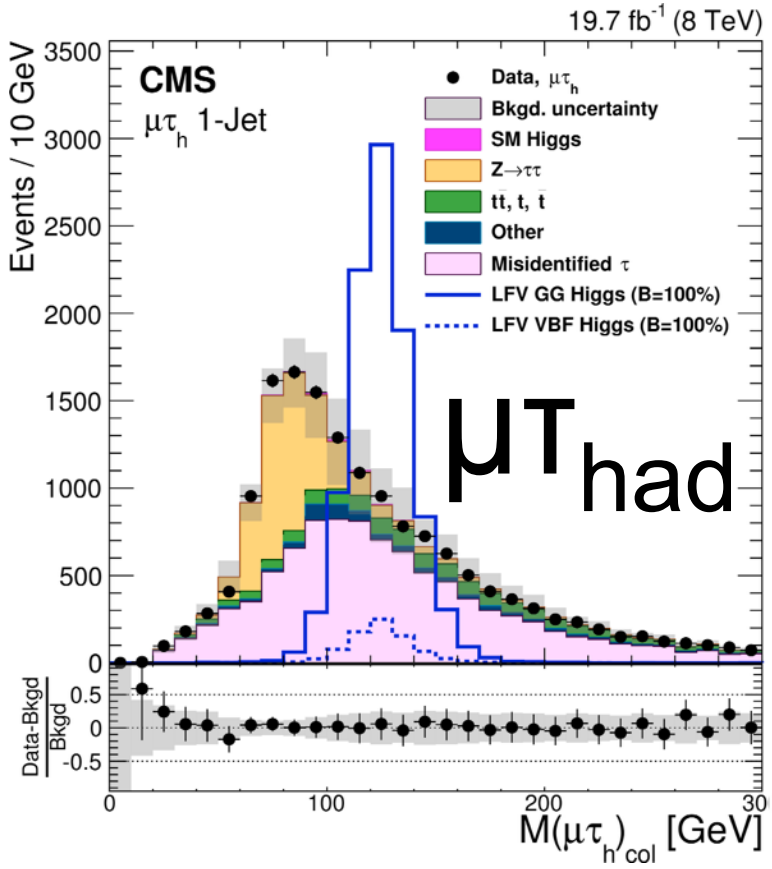
CMS-PAS-HIG-14-030

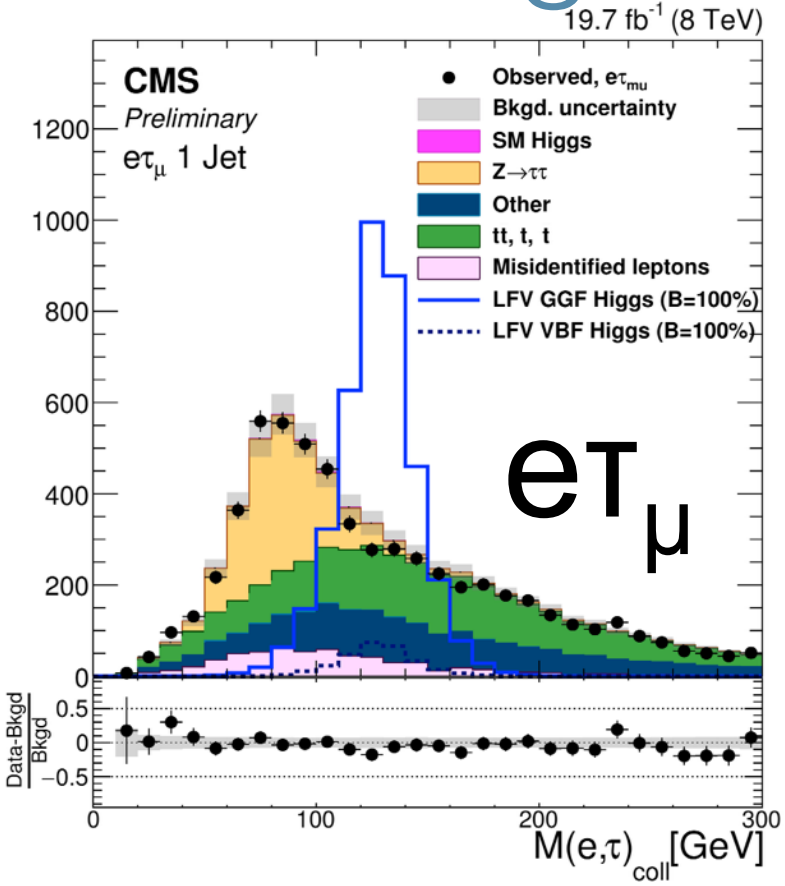
Very good agreement with the expected SM background





Background modelling



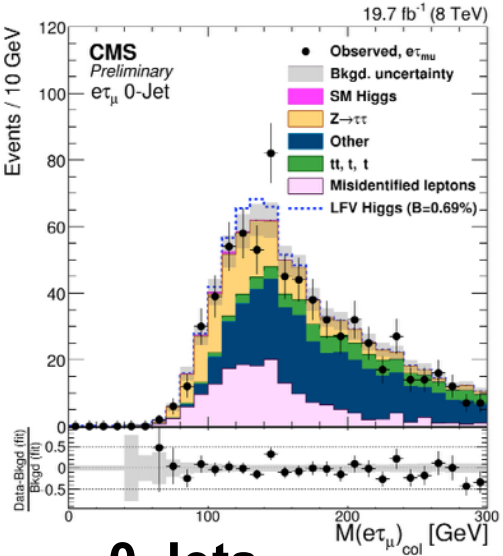


Leading backgrounds:

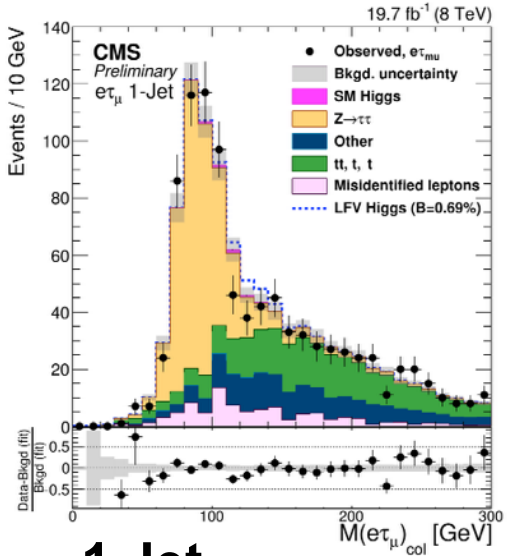
- HTauTau
- ZTauTau → **Tau-Embedding technique**
- SM backgrounds with real tau decays: top, VV → from MC
- Misidentifed Leptons (e, mu, tau) → from data

Heτ: Collinear Mass after selection

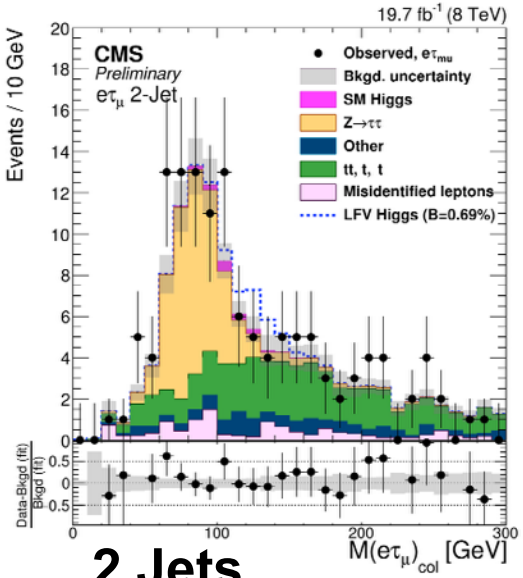
$e\tau_\mu$



0 Jets

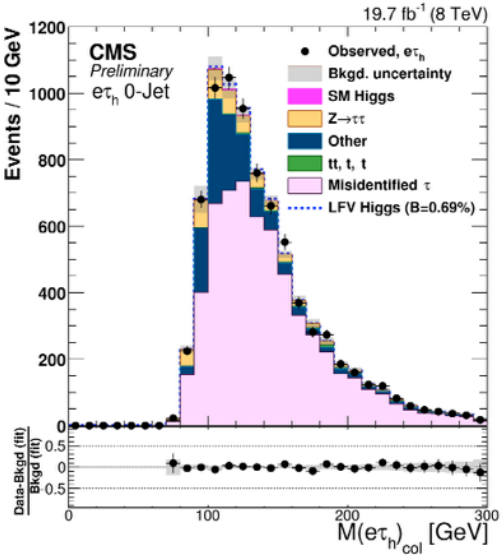


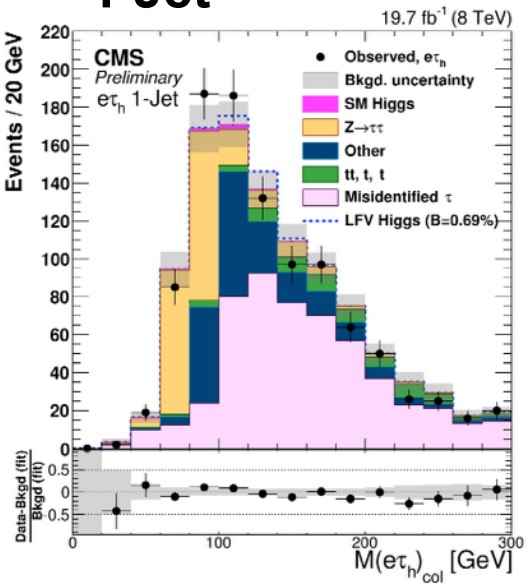
1 Jet

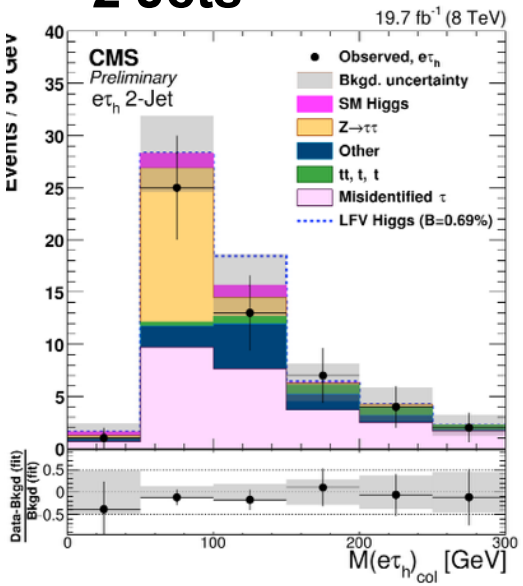


2 Jets

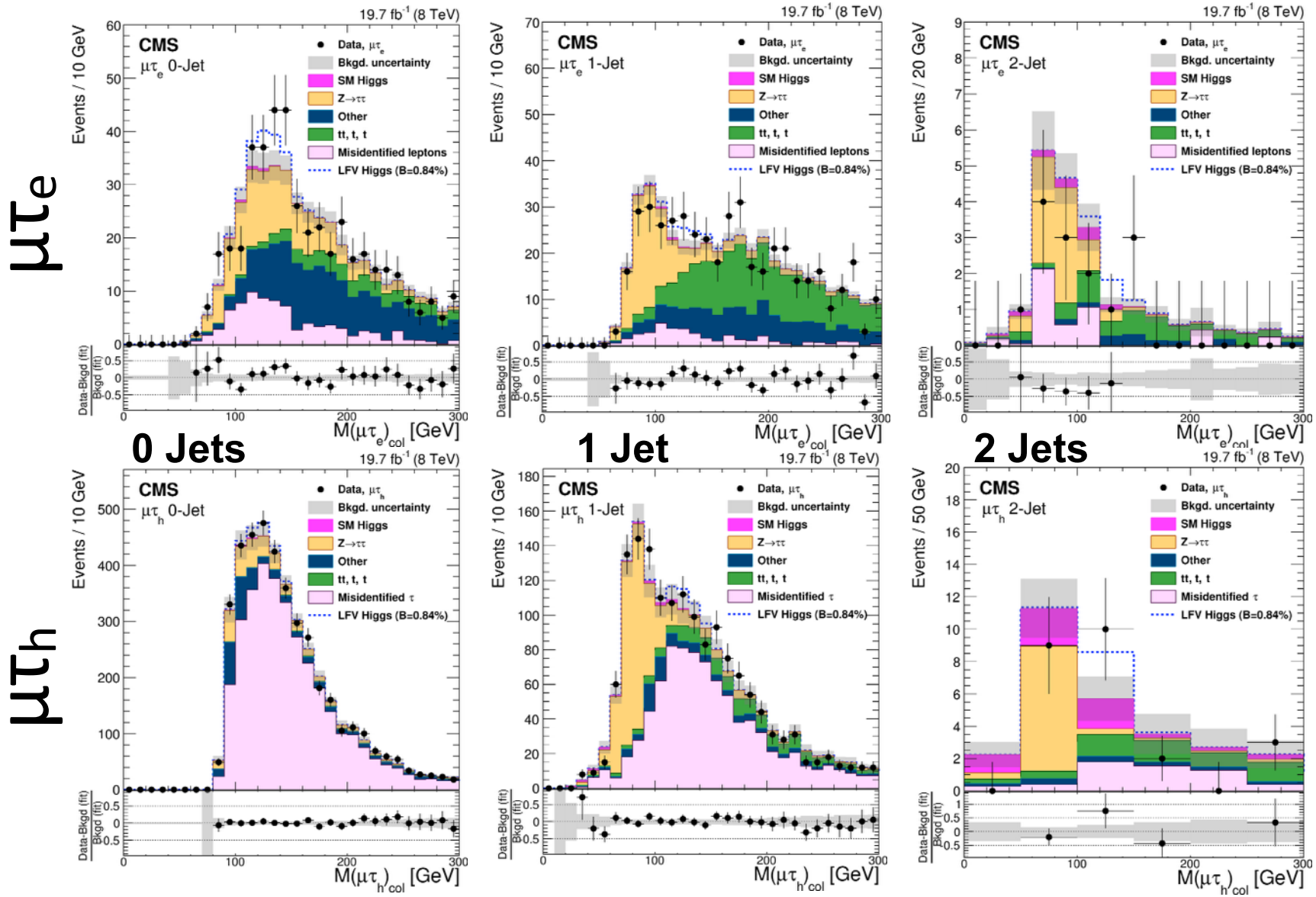
$e\tau_h$







Hμτ: Collinear Mass after selection

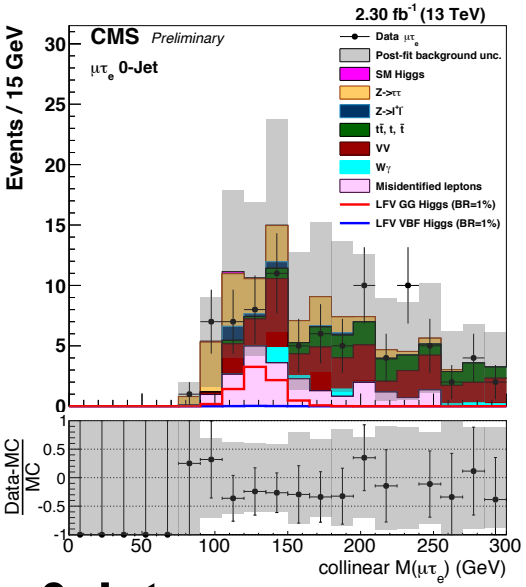


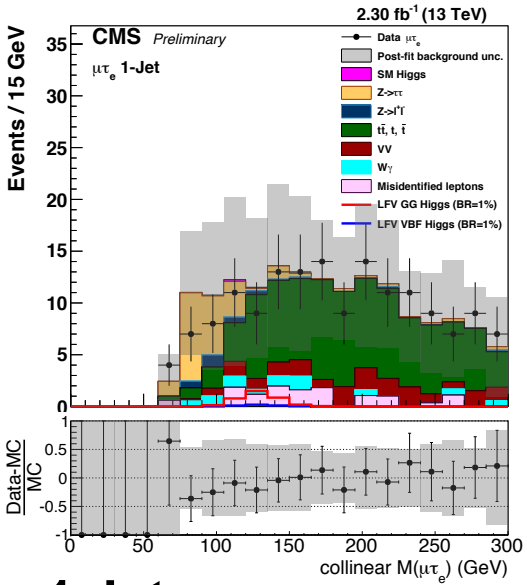
Hμτ: Collinear Mass after selection

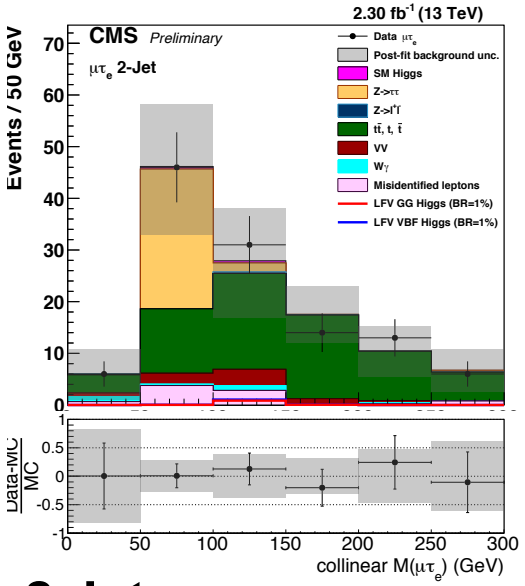
μτe

μτh

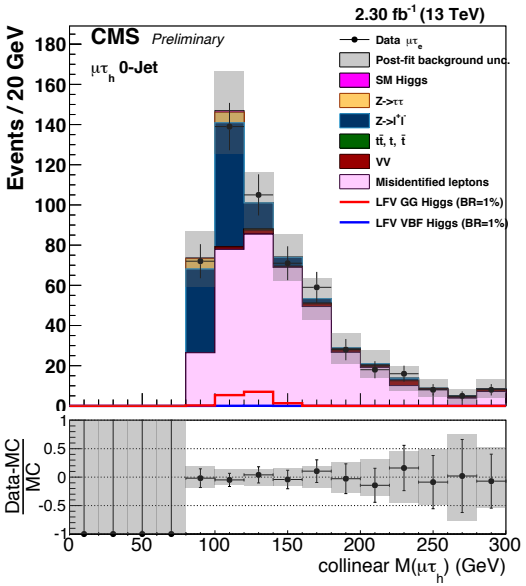
Notice the small statistics!

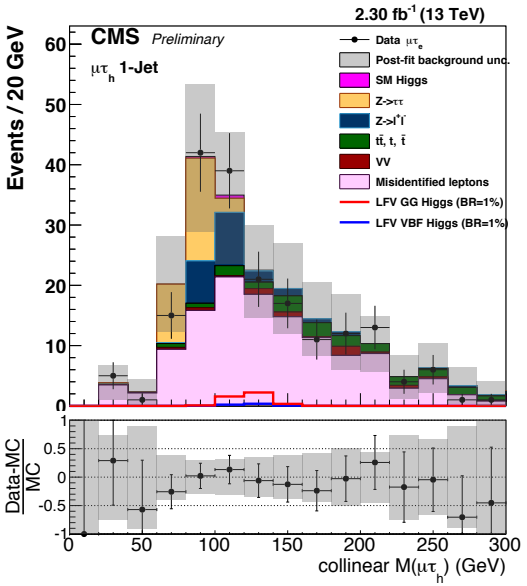


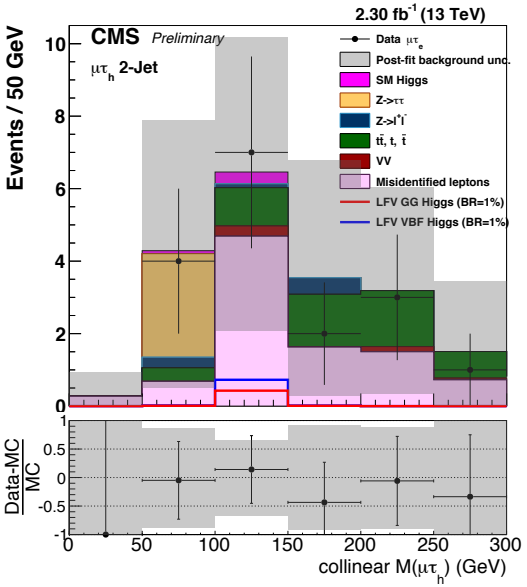


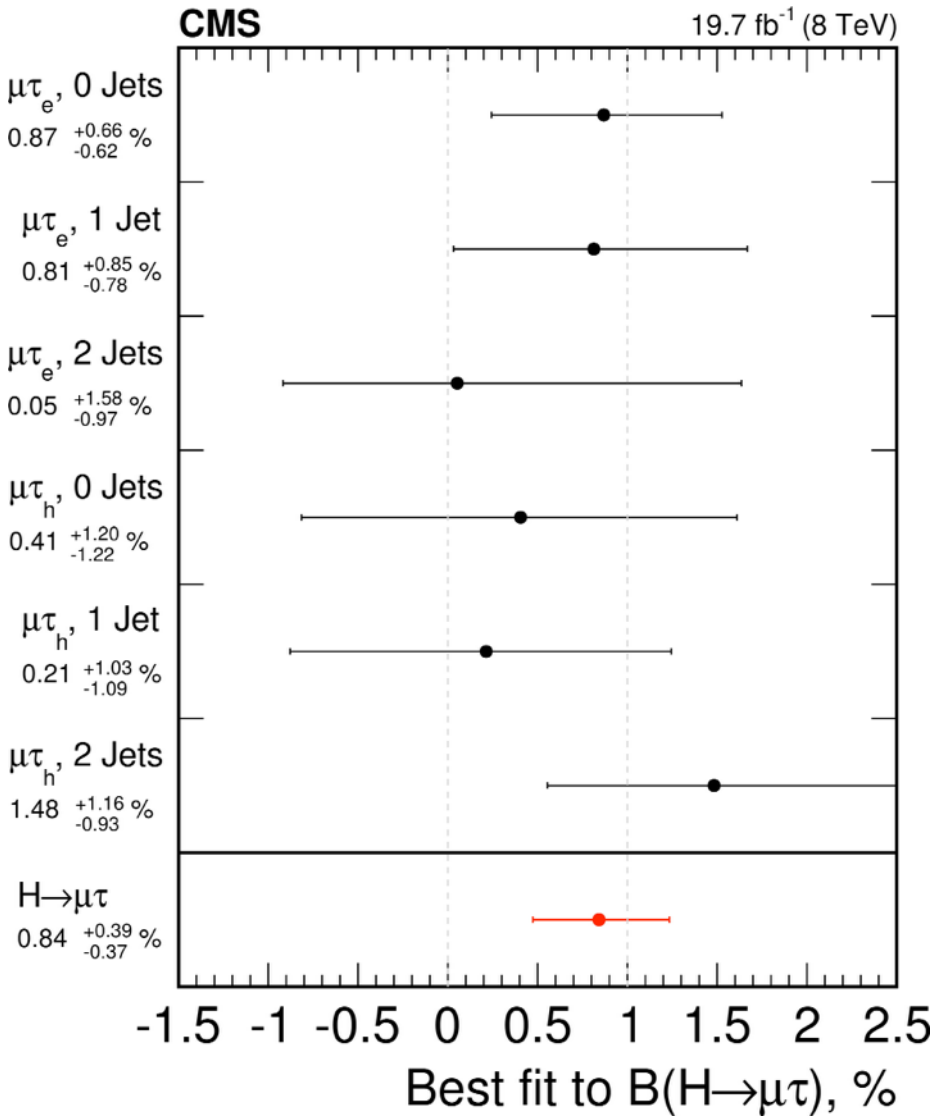


0 Jets **1 Jet** **2 Jets**







CMS: Run I Best Fit

- Small deviations per category (at most ~1sigma)
- Hemu and Heτ fits compatible with 0